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# PROGRAM TO PERFORM RESEARCH ON THE DENSITY OF THE UPPER ATMOSPHERE USING LIDAR TECHNIQUES

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This report covers a three year program to perform research on atmospheric density and related atmospheric parameters over the altitude region from a few km to approximately 100 km. The GL/LIS mobile and fixed lidar systems were utilized in this research. Field campaigns to WPAFB, OH and Greenland were included in this effort. Useful data on density and temperature were obtained to altitudes above 90 km during the WPAFB campaign, with characteristic time varying density variations observed. Various modifications and upgrades to systems capabilities were made. Density profiles were obtained under both night and day conditions using the mobile lidar. Extensive measurements of night time density/temperature profiles were made using the fixed lidar system at GL.

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# TABLE OF CONTENTS

## 1 PROGRAM OBJECTIVES

The objective of this three year program under Contract F19628-87-C-0252, commencing on 16 September 1987, has been to characterize atmospheric density and related parameters over the altitude regime from near ground level to 100 km. The measurements were made using Rayleigh, Raman, and fluorescence lidar techniques employing the GL/LIS fixed (penthouse) and mobile lidar systems.

At the start of this program, Rayleigh lidar was yielding useful atmospheric density data to approximately 75 km using the trailer system. This system utilized a frequency-doubled and tripled Nd:YAG laser and two receiver telescopes, one with a 12 diameter aperture and one with a 24 inch diameter aperture. The Rayleigh lidar results from the trailer system were to be extended to higher altitude by using a recently installed excimer laser.

The Lambda Physik excimer laser has an average power output of approximately 10 watts when operated using a XeF fill. The output wavelength is near the tripled Nd:YAG wavelength, but at a substantially higher average power than the Nd:YAG on the trailer. This combination of high power and ultraviolet wavelength produces an enhanced Rayleigh backscatter signal compared to that from the doubled Nd:YAG.

Raman lidar was to be examined as a technique to assist in sorting out the effects of scattering by aerosols at low altitudes. Sodium fluorescence lidar would be used to monitor atmospheric density fluctuations and temperature in the 85-105 km altitude range.

The program objectives included bringing both the fixed and mobile lidar systems into condition for routine data acquisition. PhotoMetrics would assist in establishing a data base of the relevant statistics of the atmosphere in the specified altitude range. Data reduction and analysis techniques developed by GL and PhotoMetrics would be used to yield the desired density related quantities from the measured backscatter intensities. PhotoMetrics was to research methods to improve both hardware and software techniques to yield the desired results.

# 2 TECHNICAL PROGRESS

## 2.1 First Year

### 2.1.1 Mobile System

Early in the first year a number of major enhancements to the GL/LIS mobile lidar facility were demonstrated a placed in operation. Daytime lidar capability has been demonstrated using the 24 inch telescope/receiver with its narrow-band Fabry-Perot etalon. High altitude lidar measurements were made using the XeF excimer laser transmitter. The 80386/CAMAC based, menu-driven, data acquisition system was installed and updated to include operation of the daytime and high altitude lidars.

The following significant technological design features were tested and verified during the demonstrations. The daytime lidar system relies on an optical frequency reference and stabilization servo which tunes the narrow receiver pass-band to the laser wavelength. This system was shown to perform reliably. The sky background rejection and overall sensitivity of the 24-inch telescope (H) detector/etalon system matched design expectations. The excimer system, which runs at 60 Hz repetition rate, requires the data acquisition system to operate at six times its previous speed. This has been proven to operate successfully due to careful design of system timing. Both of the new lidar capabilities present difficulties in beam alignment due to the lack of beam visibility. A real-time alignment mode feature in the data acquisition system compensates for the loss of a direct visual alignment check.

Toward the end of the first year of this effort certain additional aspects of the mobile system received attention. These mainly related to the possibility of simultaneous operation of the Nd:YAG and excimer lasers on the trailer and the consideration of the technical issues and possible benefits of coupling the mobile system with the Wright-Patterson 100 inch collimator facility. Simultaneous operation of both lasers would permit a downward extension of the high altitude density measurements through a newly developed two-wavelength plus Raman scheme. We attempted simultaneous operation and found the laser cooling system to be incapable of handling the load, thus requiring the specification of a replacement cooler. It was determined that two laser operation as well as analog-and-photon-counting technique would be required for operation with the Wright-Patterson collimator.

### 2.1.2 Penthouse System

Early in the first year, attention was focussed on developing the routine density data-taking capability of the penthouse lidar system. The effort addressed two major objectives, the gathering of data to support the presentation (by W. P. Moskowitz) of a paper at the 14th International Laser Radar Conference (ILRC), and preparing the penthouse lidar system for intensive data acquisition effort. The ILRC presentation, entitled "Raman Augmentation for

Rayleigh Lidar", concerned the use of an additional channel of nitrogen Raman data to normalize and improve the Rayleigh density measurements. Raman and Rayleigh measurements were made during several nights to aid in the development of the technique. Future density measurements will incorporate this Raman augmentation technique. The presentation at the ILRC in San Candido, Italy occurred at the end of June 1988. Attendance the 14th ILRC also provided opportunities to familiarize the lidar community with the current and projected capabilities of the GL/LIS fixed and mobile lidar systems and to learn of new developments in the field.

The operating plan to begin routine data taking on the fixed system imposed two immediate goals. The quality of the data must be as high as possible, and the system must be reliable and straightforward to operate---as close to a "turnkey" system as possible. With this in mind, work was done to identify "weak-links" in the system. Some electronic hardware was rebuilt to improve reliability, and several other optical and electronic components were targeted for redesign. The oscillator rod in the YAG laser was polished and re-coated to repair a damage spot on one of its end surfaces.

A significant optical system improvement which took place during this first year was the identification of "hysteresis" as a source of noise in the receiver photomultipliers. This effect had been observed as a peculiar, undocumented, non-linear response of photomultiplier tube detectors to the transient signals characteristic of lidar systems. We acquired and installed a photomultiplier in the penthouse system which incorporates "anti-hysteresis design." The measurements made using the new PMT, show no evidence of the undesired response.

Intensive lidar data acquisition began late in the first year, with the penthouse system acquiring data roughly one night per week. The routine operation of the penthouse system was supplemented with continued upgrading of troublesome or substandard components of the system. We adjusted the collimation of the Nd . AG laser to alleviate the over-filling of an aperture in the laser beam expander. The beam expander and both receiver telescopes were then adjusted for proper focus. These operations improved the quality of the data.

Following data collection, we examined the data for residual systematic effects and began work on a real-time data analysis routine. The goal of the analysis routine was the generation of real-time atmospheric density files, to yield density profiles, rather than only lidar backscatter signal files. The density files were corrected for systematic effects. The formats and file-naming conventions for these signal and density files as well as further processing and presentation schemes were considered.

Part of the upgrade process was the identification of nuances in the data collection process which can improve the quality of the data. We performed preliminary experiments during several nights of data acquisition to expand the useable dynamic range of the new anti-

hysteresis photomultiplier. By simultaneously measuring analog and photon counting output, we are able to utilize the photomultiplier in both its large and small signal regimes. Through this technique, we would expect to be able to eliminate one or even two of the three banks of photomultipliers currently required for the penthouse measurements. For the mobile lidar, which uses only one photomultiplier for each channel, this technique would allow the region of valid data to begin at a lower altitude than had previously been possible. A further spin-off of this research is the possibility of examining thin cloud layers in more detail. Clouds typically occupy only two or three range intervals using the photon counting system and frequently saturate the detector. The analog modules we used for these experiments were capable of spatial resolution sixteen times as fine as that of the photon counting system, and saturation effects were eliminated.

## 2.2 Second Year

### 2.2.1 Mobile System

Early in the second year work continued on the planning and preparation for GL/LIS's future involvement with the Wright-Patterson 100-inch telescope. Activities in the trailer included hardware repair and upgrade, demonstration of the mobile lidar capabilities, and planning for remote operation. We repaired and redesigned a laser trigger control box to eliminate spurious laser triggers. The Nd:YAG and excimer lasers were operated and proper operation was verified. A malfunction was repaired in the trailer daylight lidar system which utilizes a high voltage amplifier unit to drive a piezoelectrically tuned etalon. A malfunctioning transformer in the amplifier was replaced. A preliminary data set was acquired in the trailer using combined analog and photon counting techniques. This activity pointed out areas to be addressed in finalizing the design of a combined analog and photon counting system.

To assist in the planning of field activities for the mobile lidar, we helped to produce a timeline of anticipated trailer capabilities. The timeline included current experimental techniques which we expected to bring on-line before the next field trip. Another tool for the presentation of capabilities was a data quality plot. The signal-to-noise ratio for the lidar data depends on averaging time, altitude resolution, and altitude. A complete data plot thus need four dimensions, and furthermore, each lidar system needs a different plot. We reduced the dimensionality by identifying the most useful set of coordinates. This allows the data quality to be plotted as a family of curves in two dimensions. Such plots were produced for each of the penthouse and trailer lidar systems.

Also, early in the second year, Warren Moskowitz accompanied Dr. Phan Dao on a trip to the Wright-Patterson telescope facility. Our task was to identify possible configurations

for the coupling of the GL/LIS mobile lidar and the 100-inch telescope and to anticipate potential difficulties. We examined the facility, noting critical dimensions, and discussing current operating difficulties with the staff.

The excimer laser in the mobile lidar facility received considerable attention in preparation for the mission to WPAFB. There was evidence of a large gas leak from the laser cavity. Part of the laser was dismantled and found to be leaking at the pre-ionization pins. We conferred with other users of this model laser and found this to be a common and recurring problem. It was suggested that the only permanent repair was to upgrade to teflon pins instead of using the current ceramic pins. The upgrade would require a change of the entire preionization mounting plate. Lambda Physik, the excimer laser manufacturer, was not prepared to perform this upgrade until there was further evidence of a leaking problem. Lambda Physik agreed to effect the proper repair if the laser showed any more sign of leakage. We replaced the dozen leaking pins with replacement ceramic pins, and leak checked the laser.

During leak checking of the excimer, which involved supplying power and coolant water to the laser, the coolant reservoir was found to have drained dry. One of the coolant fittings, internal to the laser head, was loose. We sealed and tightened this and the other water fittings in the laser head. The coolant system, which is a closed cycle refrigerated system, was known to be insufficiently powerful to cool both the excimer and the Nd:YAG lasers in the trailer operating simultaneously. This is the mode of operation that was planned for the work at WPAFB with the 100-inch telescope. A new cooler was installed and we obtained and installed the proper tubing and couplings to connect to the existing plumbing.

When the excimer laser returned to proper operation,a technique was developed to measure the angular divergence of the beam. The beam was focussed, at low power, using a 20 cm lens. An image of the focus was produced by wiping an aluminum plate through the focal region with the laser operating at high pulse repetition rate. The smallest of the melt patterns on the plate resulted from the tightest focus of the beam, and its size and shape was assumed to have been representative of the laser focus. The dimensions of the spot, divided by the focal length of the lens give the divergence of the laser. Analysis under one of PhotoMetrics' analytical microscopes showed a divergence of 0.68 milliradians. This is a pessimistic value for the following reasons. The laser was operating very weakly due to contaminated laser gas, and it is believed that higher gain in the laser will reduce the divergence.

The analysis of the aluminum melt pattern showed a strongly melted and distorted central region surrounded by a weaker melt. The surrounding region might have been splashed material from the central melt. We used the full diameter of the surrounding region to arrive at the 0.68 mr figure. If the central region is more representative, the divergence is a

factor of 1/3 to 1/6 of the value given.

Before performing the final divergence tests, we noted that the laser cavity needed alignment. We adjusted the mirror alignments to minimize the divergence and maximize power. Familiarity with these adjustments would prove useful during future trailer operation. The primary motivation for performing the divergence tests involved the design of a beam expander to be used during the WPAFB activities. The receiver field-of-view was to be limited to 0.24 milliradians. The laser divergence needed to be reduced to less than this value to obtain full capability from the high altitude measurements. On the other hand, the excimer beam was large--one inch in the horizontal direction. Beam collimation involves expanding the beam by the same ratio with which the divergence is reduced. An expansion ratio of 1:2.5 was selected as the best compromise between beam divergence and optics dimensions.

A design for a beam expander was developed which used refractive optics. The entire assembly was adequately compact to mount on a single gimbal mount, permitting steering of the excimer beam without the use of an additional steering mirror.

The high altitude detector package, which normally resides on the 24 inch telescope in the trailer, contains an etalon for use during daylight conditions. The etalon itself is in a cylindrical housing containing two mirrors held parallel by piezoelectric actuators. The unit requires a mechanical prealignment to set the parallelism of the mirrors. We performed the mechanical alignment to simplify future alignment of the daylight system.

While our attention was turned to etalon systems, it was suggested that we consider the method of operation of the University of Wisconsin triple etalon lidar. This system uses a 35 cm diameter telescope and has a complex combination of diameter, etalon bandpass, and angular acceptance for a Fabry-Perot system. Our analysis showed the effective use of the 35 cm telescope is only 2.1 percent, which puts is far lower in optical throughput than the trailer daylight system.

In normal operation the raw data acquired by the lidar systems is reduced to remove the peculiarities of the lidar hardware, including the saturation effects of the photomultipliers and counting electronics, and any attenuation or shutter mechanisms in the optical path. We have termed this reduction "preanalysis" since the result is atmospheric density, not a scientific interpretation of the atmospheric effects. Dr. Meriwether undertook the primary scientific analysis of the data from the high altitude fixed lidar system (penthouse). To assist in his effort, the preanalysis phase of the analysis was formally made a separate task.

We developed software to perform the preanalysis of the data from both the mobile and fixed lidars. Several upgrades of the preanalysis package were made. The first set of upgrades permitted simpler operation of the software through prompted responses. Processing of "wildcards" in data file names and automatic time sorting of the selected files was added

next. The package can be instructed to run on an entire night's data, taking several minutes to generate a single output file containing all of the density profiles. The resulting data files can be in excess of one million bytes long.

The question of the best mode of transporting these files produced three answers: A nine track tape unit was attached to the computer and we used a procedure for transferring the data in a format readable by the GL VAX computer. This method was abandoned in favor of a combination of floppy disk transfer to
local PC computers and network transfer to the VAX. The floppy disk transfer method is currently being used.

The preparation for future field use of the trailer included reinstallation of the control room electronic equipment in a floor mounted rack. We reviewed all of the cable connections after this installation, and tested the components of the system to verify their proper operation.

The excimer laser beam was currently steered by a mirror mount equipped with motorized micrometers which were remotely operable from a joystick unit. During one of the tests of lidar acquisition, it was found that the micrometers were not moving the mirror properly. There were two problems, the micrometers were not properly mated with the mount, and the electronic cables were intermittent. We counterbored the mirror mount and added spacers to accept the micrometers properly, and repaired the motormike cables.

The data taken in the trailer had exhibited an occasional noise feature caused by the firing and extinguishing of the Nd:YAG laser flashlamps. The noise feature was found to disappear when the amplifier/discriminator unit on the 24 inch detector was clamped firmly to the photomultiplier housing. We designed permanent clamps for this purpose, and began constructing an adequate number to outfit all of the detectors on the trailer.

As part of the preparation for the WPAFB mission, the camx data-taking software was upgraded for combined, asynchronous YAG and excimer laser operation. In the process, an error was discovered in the interrupt handling routines provided by the C-86 compiler used to develop the software. The error, which caused the computer to "hang-up" when several pieces of hardware called for attention simultaneously, was corrected. One result of the repair to the compiler was the capability to use LAN software. Desk-Link LAN software had been acquired to interconnect the data-taking and analysis computers in the trailer. The software operates in background and allows the analysis computer access to the data even during data acquisition. Until the repair of the C-86 compiler, attempts to transfer data during acquisition suspended computer operation. Camx was upgraded to eliminate the dead-time associated with operator initiated storage of data and re-starting of data acquisition. The software can now be instructed to automatically acquire and store data.

A refractive beam expander for the excimer laser was built, aligned and tested. The

unit brought the excimer laser divergence below 0.22 milliradians for use with the Wright Patterson telescope. We aligned the expander by adjusting the lens spacing to collimate He-Ne laser light. The lens separation was then readjusted by a calculated distance to compensate for the dispersive refractive index difference at the excimer wavelength.

At one point, toward the middle of the year, the trailer Nd:YAG laser suffered substantial thermal damage due to loss of coolant water to the laser heads during operation. The Nd:YAG rod in the amplifier head, and the glass blocks surrounding the flashlamps and Nd:YAG rods were shattered. The glass blocks serve the dual purpose of directing the coolant water flow and conducting the flashlamp light to the Nd:YAG rods and the reflective MgO coating.

The loss of coolant was probably due to a coolant leak in the excimer laser. The two lasers now share a common cooler unit. With the two lasers connected, the YAG laser was left without a coolant flow interlock. We corrected this flaw by installing a closed loop coolant circulator with a flow interlock on the YAG. The circulator came from the penthouse YAG laser, where it was no longer needed because the former trailer cooler had replaced it. The closed loop circulator solved another problem in the coolant circuit. We were informed by Lambda Physik that the excimer laser would be slowly damaged by the use of deionized water as a coolant. Ordinary tap water was suggested. The YAG laser requires deionized water. The closed loop circulator for the YAG permits both lasers to share the cooler while maintaining separate coolant fluids.

During this mid-year period, the gas leaks around the preionization pins in the excimer laser reappeared. Arrangements were made for Lambda Physik to install an upgraded preionization plate in the excimer laser. We participated in the upgrade procedure just prior to the first trip to Wright Patterson.A considerable volume of laser gas was consumed by the repairs, as well as the extensive operation of the excimer laser for data acquisition. We purchased the required pure gasses and mixtures.

We ordered and installed a solid-state 400 Hz power converter for the trailer radar system. The power was previously provided by a motor/generator unit which failed approximately mid-year. The radar units received much attention during the Wright Patterson trips. The trailer radar was inoperative on arrival at Wright Patterson for the first exercise. To return it to proper operation a defective keep-alive rectifier cartridge was replaced with a string of four silicon rectifiers and divider resistors, signal diodes were replaced, and relay contacts were cleaned. The radar operated for several days and failed again prior to our return to Massachusetts. The T401 transformer was identified as defective.

On our return to Wright Patterson, we shipped the penthouse radar unit to serve as a back-up in the event the trailer radar resisted our attempts to repair it. This proved necessary,

as an intermittent problem persisted after installing the replacement transformer and repairing several broken solder joints. The penthouse radar also failed to function properly upon installation in the trailer. The situation was remedied by replacing several microwave diodes and adjusting the klystron attenuators.

The 32 cm coaxial lidar receiver on the trailer had been suspected of less-than-optimal performance. Upon inspection, we found an inherent misalignment in the design of the filter-holder/beam-splitter box. The offsets of the optical paths had not been taken into account, resulting in clipping of the optical path by the edges of the filters. To correct the problem, two new aluminum pieces were machined.

Noise pick-up had been a severe problem in the trailer. The YAG laser and some of the control electronics produce noise which is detected on the control and signal lines. We spent some time tracking down the sources and antennas for the noise pick-up. The effort focussed mainly on ground loop problems between the photomultiplier housings and the amplifier/discriminator units.

The Wright Patterson 100 inch collimator telescope was used to collect the backscatter from the excimer laser beam. To detect the signal, the H-detector, which normally resided on the 24 inch telescope in the trailer, was modified and mounted on the 100-inch telescope. An adapter frame was constructed to position the detector at a suitable distance relative to the focal position of the telescope. In addition, new lenses were installed at the entrance of the H-detector to couple the detector optically.

During the first trip to Wright Patterson, the modified H-detector was installed on the 100-inch telescope and tested optically. The focus of the telescope was not at the position used in the H-detector modifications. New transition optics were designed around the proper focus position. The redesigned transition optics were installed in the H-detector upon returning to Wright Patterson. Proper operation was verified by observation of stars traversing the field of view.

To operate the excimer and YAG lasers simultaneously and asynchronously, the H-controller was modified to produce laser and data system synchronization pulses. Prior to these modifications, the controller served as a slave unit which locked to synchronizing pulses from the 32 cm coaxial lidar controller. The H-controller can now serve as a master as well as a slave unit. The anti hysteresis Hammamatsu R878 photomultipliers were installed and tested in the three optical channels of the trailer system. The strong signals anticipated with the 100-inch Wright Patterson telescope required the anti-hysteresis properties of these PMT's.

We participated in a total of four data-taking campaigns to WPAFB during the year. The trailer system experienced several noise pickup problems during this series. Solving them was difficult because of the ambiguities created by multiple, sporadic noise sources. Ground

loop effects between the trailer and the 100-inch telescope building were observable on an oscilloscope. Ripples as large as 1 volt were sometimes preventing discriminated photon pulses from reaching the trigger threshold of the multi-channel scaler (MCS). Spikes of several volts were erroneously registering as photons. In order to solve this problem, we constructed common-mode rejection and bandpass filters. Optical fiber coupling is a better long term solution, but the electronic filters have been effective, and were rapidly and inexpensively implemented.

The ground loop problem was exacerbated by an error in the specifications of the Lecroy 3521A MCS units. The inputs, which are referred to as meeting TTL specifications, have a threshold at 3 volts. True TTL should have a threshold of 2.4 volts. The pulses from the photon discriminators are 3.1 volts, and hence are able to trigger the MCS only when transmission line attenuation and ripple are minimal. The threshold of the MCS units is determined by the value of one of the input resistors. We changed this resistor in all of the MCS units, both in the trailer and the penthouse, to bring the threshold down to 2 volts.

During initial running at WPAFB, we observed optical cross-talk between the YAG UV channel and the excimer channel during simultaneous operation. This was cured by synchronization of the two lasers to avoid each other.

### 2.2.2 Fixed System

Routine data acquisition with the penthouse system continued, including operation of the Raman lidar. Our support for the penthouse system hardware included a realignment of the Nd:YAG laser optics and electronic timing delays. During this period, working with Dr. Meriwether of AFGL, we further defined the data exchange format. PhotoMetrics was given the responsibility for generating software which would produce density data files from the raw lidar data. The format was agreed upon early in the year and work began on the density routines. Future data exchange will be simultaneous with data acquisition. To proceed in this direction, we tested several data transfer programs which can exchange data between two PC computers as a background task. We also attached a tape drive to the penthouse data-taking computer to expand the available means of data exchange.

After some moths of routine operation, the penthouse lidar began to show diminished signal. We retuned the laser, improving its output power and mode pattern. Upon further examination, the frequency tripler, which generates the ultraviolet light, was found to be attenuating 44% of the total laser power. The tripler , which consists of a nonlinear crystal sandwiched by quartz windows, was dismantled. The antireflection coatings on the windows had received considerable damage. Replacement windows were obtained from the manufacturer.

Up to this point, the data taking software operating in the penthouse had not been acquiring data on background radiance. Although the background had been assumed negligible during the nighttime operations, the focus on detailed data analysis revealed that this was not the case. We modified the acquisition software to include the background data in the data files. The addition was included in the preanalysis software by modifying the configuration files responsible for recording the hardware specifics.

New, low hysteresis photomultipliers were acquired for all of the channels of both the penthouse and trailer systems. The new PMT's required eventual replacement of sockets in all of the photomultiplier housings. Two types of PMT housings were in use. The cooled housings used in the trailer and on the high altitude green channel in the penthouse had removable sockets. We acquired the correct sockets for these housings. The uncooled housings were not as easily modifiable. We acquired updated housings for all of these channels. The amplifier/discriminator units from the old housings would ultimately be removed and packaged separately for use with the new housings.

The satellite avoidance alarm program, which had been running on a separate computer, was rewritten. The change was made to prepare for its incorporation into the data acquisition software. The computer which had been running the alarm program is now used for real time data analysis, while the alarm runs silently in "background" in the data acquisition computer. The alarm will ultimately shut off the laser automatically, eliminating the need for a human response.

W. Moskowitz and G. Davidson discussed various aspects of the GL/LIS mobile and fixed lidar systems in two papers presented at the 1989 Conference on Lasers and Electro-Optics, held in April in Baltimore, MD. W. P. Moskowitz's paper reported on a technique to produce absolute density measurements using UV, green, and Raman lidar.

## 2.3 Third Year

### 2.3.1 Mobile System

This third year of the program started in October 1989 with a trip to Wright-Patterson AFB for lidar data acquisition at the 100-inch telescope facility. The 24-inch telescope was brought back into operation for simultaneous YAG and excimer measurements. The excimer data was collected using the 100-inch telescope. The receiver package from the 24-inch telescope had been borrowed for use on the 100-inch telescope until the end of the second year, when a new receiver was installed on the 100-inch telescope. The last component was returned to the 24-inch telescope at the beginning of this year, bringing both systems into full operation. Data acquisition continued for several weeks at WPAFB.

On a return trip to WPAFB during January 1990, we found substantial damage due to frozen laser coolant. The power to the trailer had been disconnected for a few days. The excimer laser suffered most of the damage. We dismantled the excimer laser and repaired the damage. New thyratron coolant oil was installed. The water flow switch was leaking and had failed to operate, so it was re-built. The YAG heat exchanger had some damaged plastic pipe fittings. To avoid a recurrence, antifreeze was added to the laser coolant.

The YAG rod in the trailer amplifier head has been operating with a large damage spot for several months. We obtained a replacement rod and installed it during the third trip to WPAFB. The power in the trailer YAG laser was found to be deficient even after replacement of the rod and flashlamps because two of the four flashlamps were not firing. The problem was traced to a faulty solder joint in the YAG power supply and repaired.

The data storage capacity of the trailer's data acquisition computer was increased through the installation of a new 80 Mbyte hard drive. This was deemed necessary because of the tremendous numbers of files which had been generated at one-minute intervals under automatic acquisition.

The excimer laser was observed to have a slow gas leak from the cavity during the third trip to WPAFB. The leaking part was identified and replaced. During one of the trips to WPAFB the signal from the 100-inch telescope had been examined for the presence of electrical noise. The problem was alleviated by properly grounding the trailer to building 622 which contained the 100-inch telescope. The daytime lidar system was brought into operation. Data was acquired during the daytime and through the night to monitor the stability of the Fabry-Perot etalon with time and changes in ambient temperature. The etalon feedback system requires a 10 Hz synchronization signal. The trailer rack panel was rewired to provide it. The last trip to WPAFB concluded with the packing of the trailer and its contents for shipment to Greenland.

A second lidar receiver channel was added to the 24-inch telescope. This channel protrudes from the detector housing and uses a dichroic beamsplitter to receive the UV light while the main channel continues to receive the green light. This allows for simultaneous excimer and doubled-Nd:YAG lidar using the 24-inch telescope alone. The necessary components were designed and fabricated at PhotoMetrics and brought to Greenland for installation in the field. An additional field-installed modification was made on the Motor-Mike actuated steering mount for the Nd:YAG laser transmitter. The modification allows for more reliable operation of the mount and was necessary since it would be solely responsible for beam steering during the Greenland campaign.

During the final months of this effort two campaigns were made to Sondre Stromfjord, Greenland. A large volume of data was acquired with the Nd:YAG and excimer lidars in the

trailer during these missions. The purpose of the campaign was the observation of noctilucent clouds and measurement of the conditions under which they form. The first of the two trips was primarily for set-up and system checking. Much hardware maintenance, repair and upgrading was needed to accomplish the data acquisition.

Operation in Greenland used a different laser synchronization scheme than that used previously. The electronics were modified to generate the proper synchronization pulses. The pulse repetition rate of the Nd:YAG laser has been 10 Hz. We checked with Continuum, Inc.(formerly Quantel, the laser manufacturer) about the consequences of increasing the data accumulation rate by raising the repetition rate beyond the normal laser specification to 11 Hz. This change in operation was tested successfully in the trailer.

The 1/12 hp circulator pump in the laser coolant refrigerator had been marginal to support simultaneous operation of the Nd:YAG and excimer lasers. We acquired a replacement 1/3 hp pump and installed it at the start of the second trip to Greenland. The increased pressure in the coolant system caused a fitting at the back of the laser coolant refrigerator to leak slowly. The lasers began operating erratically when coolant supply became insufficient. The leak was repaired and the coolant refilled.

The majority of the Nd:YAG data were acquired using the daytime etalon system. The etalon required several realignments during setup and testing. Extended operation with the etalon had not been done previously and procedures were developed to monitor and align the etalon. The etalon system had not previously been operated under the conditions of widely varying temperatures which we found in Greenland. Measurements in the etalon thermal housing revealed large temperature excursions. A new heater assembly was manufactured in the field and installed. Different temperature settings were required for the new heater assembly owing to the improved thermal contact with the band-pass filter. The temperature was adjusted to optimized signal transmission.

During the lidar observations, photographic equipment was operated at a nearby site. We assisted in the operation of the equipment, including the use of a backup camera during the one night of noctilucent cloud sighting. To prepare for the possibility of strong lidar returns from the noctilucent cloud layer, we brought a DSP2090 scaler for the CAMAC crate which was capable of improved resolution by a factor of two over the capability of our usual photon counting equipment. The 75 meter resolution of this instrument would have made structure in the cloud layer more evident. The unit was installed, software modifications made, and lidar tests performed, but it's use was not required during data acquisition.

Upon return to Massachusetts, the large library of data files from Greenland required examination and analysis. To assist in this effort, a new feature was added to the CAMX data acquisition software. It is now possible to sum selected files in a buffer during acquisition or

during review. The buffer may then be stored as a separate file. Preliminary examination of the data was performed using the new summation feature, and nightly averages of acceptable files were presented.

Performance of the system during the campaign was assessed by comparing the signal benchmarks with theoretical predictions and past performance. The system was found to be operating at peak efficiency attained in any of the past trailer or penthouse configurations. Furthermore, the best efficiencies in all of the configurations were found to agree quite well. Theory predicted signal levels four times greater than experiment until more realistic values were provided for atmospheric transmission. We calculated the revised values using LOWTRAN.

### 2.3.2 Fixed System

The penthouse safety radar was returned to the penthouse and reinstalled. It had been shipped to WPAFB near the end of the last year to replace the trailer radar while that set was being repaired. Both sets were now operate properly. The penthouse lidar system had a third data channel installed.

Early in the third year of the program it was decided to bring the penthouse dye laser capability back into operation for measurements of the sodium layer. We examined and inventoried the penthouse narrow-band dye laser system to identify any obstacles to its return to operation. All components were found to be present, although needing cleaning, and suggestions were made for laboratory repairs and improvements. The Olivetti control computer was operated and down-loaded with the necessary software.

It was noted that the second, wide-band Lambda Physik dye laser had not yet been operated. It was currently configured for 308 nm (XeCl excimer laser) pumping and would need new pump optics for Nd:YAG or XeF excimer pumping. The Laser Technics wavemeter was brought back to operating status, and demonstrated by measuring the wavelength of a HeNe laser. The communications interface to PC computers was reworked and control from a PC was demonstrated. Optical fiber components were acquired to enable the admission of laser light into the wavemeter from various remote sources without realignment.

The Gavintech wavemeter is a second, higher precision wavemeter for use in sodium lidar temperature measurements. We returned the Gavintech wavemeter hardware to operating condition.

Two attempts were made to observe returns from the sodium layer using the narrow-band Lambda Physik dye laser operating with broad-band output. The weak laser beam was successfully aligned into the receiver telescope field-of-view on the second night by using a newly installed spotting telescope mounted to the side of the 36-inch receiver telescope. A

poorly collimated dye laser beam was partly to blame for the difficulty in alignment. We focussed the final stage of dye laser for collimated output, but the linewidth of the dye laser was too broad to efficiently excite the sodium resonance.

Successful sodium lidar will require a frequency-stable laser source and reliable methods of determining the operating wavelength. A sodium cell can be used as a monitor of laser wavelength once the laser is operating in the vicinity of the sodium resonance. A cell was acquired for this purpose from Opthos, Inc. Alternative laser sources are being researched. One candidate, the mixing of 1.06 micron and 1.32 micron Nd:YAG laser light has been under development for several years at Lincoln Laboratory. We visited Lincoln Laboratory to observe and discuss the most recent developments in this work and assess the applicability of the technique for our measurements.